The Effects of a 1998 Observing System Change on MERRA-2-Based Ozone Profile Simulations

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O_3 Simulations Using MERRA-2 (1980-2016)

- We use ozonesonde and Aura data to evaluate the O_3 profiles in two model simulations (1980-2016) that use NASA's Modern-Era Retrospective Analysis for Research Applications, Version 2 (MERRA-2; Gelaro et al., 2017; J. Climate) meteorology and Global Modeling Initiative (GMI) chemical mechanisms:

M2 GMI Replay (Orbe et al., 2017)

- 0.625°x0.5°horizontal resolution, 72 vertical levels
- Uses Replay technique to recalculate u, v, T, and p from 3hr average MERRA-2 fields (two forecasts per time step)

GMI CTM (Strahan et al., 2016)

- 1°x1.25° horizontal resolution, 72 vertical levels
- Driven by 3hr average MERRA-2 meteorology fields in a traditional offline CTM
- Uses a newer version of the GMI chemical mechanism

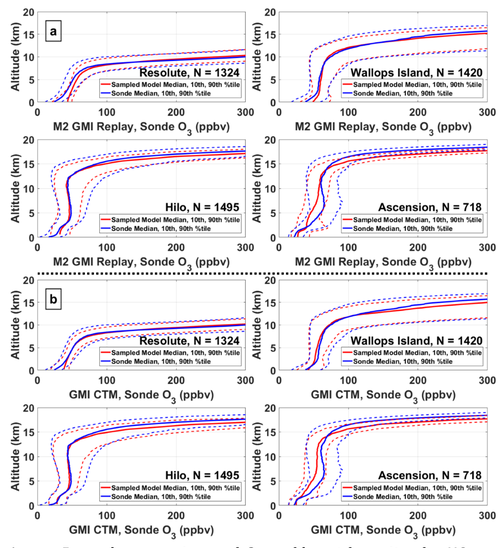

Fig. 1: Example comparisons of O_3 profiles at four sites for M2 GMI Replay (top, a) and GMI CTM (bottom, b). Sonde O_3 is in blue, with coincident model O_3 output in red. Sites shown here represent four latitude regions: Polar (Resolute), Midlatitude (Wallops Island), Subtropical (Hilo), and Tropical (Ascension).

1) How well do models driven by MERRA-2 meteorology simulate historical O_3 (1980-2016), particularly from the UT/LS to the mid-stratosphere?

2) Are there major differences in how Replay and CTM simulate O_3? Do potential differences in model transport lead to different model/observational agreement?

1998 Assimilation Changes (ATOVS)

- Profile comparisons of M2 GMI Replay and GMI CTM with midlatitude ozonesondes show changes from 1980-2016 (**Fig. 2**, right)
- Starting in 1998, the MERRA-2 assimilation system incorporates data from a new generation of satellite sounders, known as **ATOVS** (Advanced TIROS Operational Vertical Sounder; on NOAA-15)
- The change from TOVS to ATOVS introduced a step change in O_3, particularly in GMI CTM (**Fig. 2**, circle on bottom)
- The shift in LS O_3 in GMI CTM leads to a ~10 Dobson Unit (DU) increase in midlatitude total O_3, worsening the agreement among models, and sondes/satellites

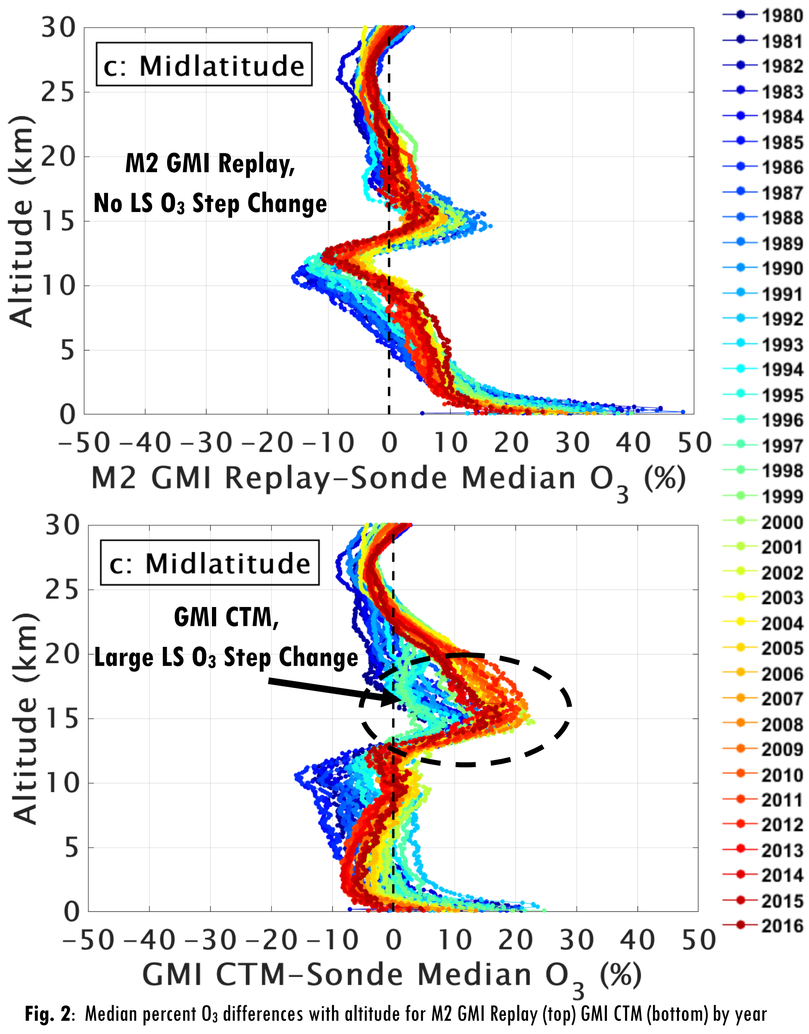

Fig. 2: Median percent O_3 differences with altitude for M2 GMI Replay (top) GMI CTM (bottom) by year from 1980 to 2016 (colors). A black circle highlights the step change in GMI CTM lower stratosphere O_3. Comparison is composited from 19 midlatitude ozonesonde sites.

- Examination of the MERRA-2 meteorological assimilation v wind Increment Analysis Units (IAU) in the UT/LS quantifies a model step change in 1998 (**Fig. 3**, below)
- The IAU change after 1998 indicates that the new ATOVS observations are impacting the MERRA-2 assimilated wind fields, especially in the tropical upper troposphere
- Prior to ATOVS, high vertical resolution observations in the tropical UT/LS were sparse. More observations became available to influence the MERRA-2 assimilation, which tends to diverge from the MERRA-2 analysis state in larger amounts after 1998 (larger IAU)

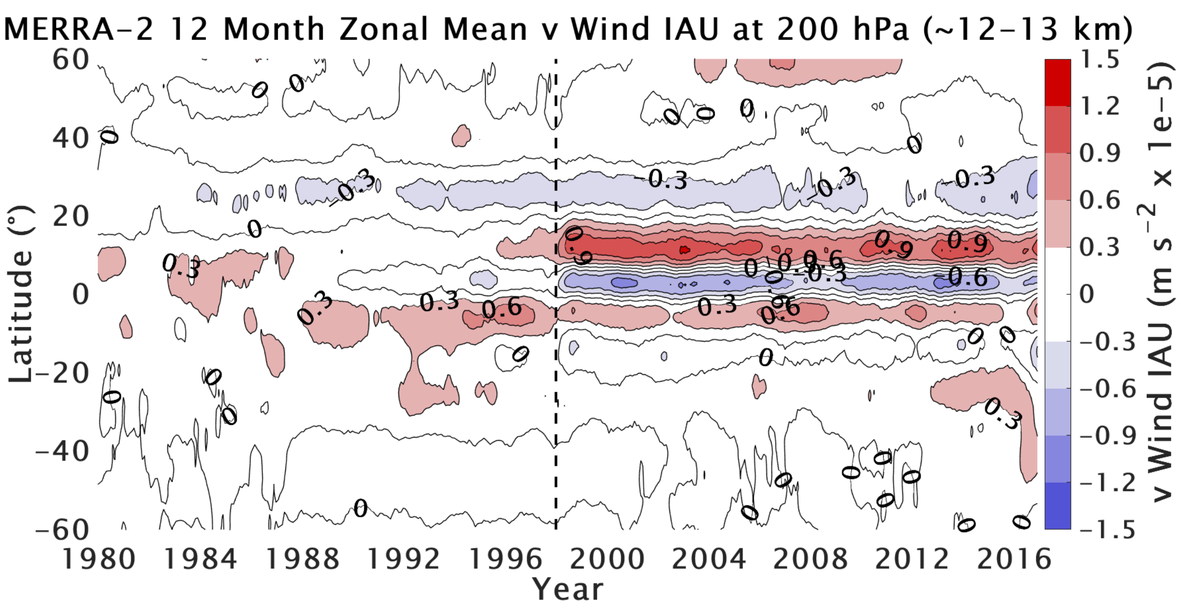

Fig. 3: Smoothed 12-month zonal mean of MERRA-2 200 hPa (~12-13 km altitude) v wind IAU from 1980 to 2016. Negative v IAUs are shown in blue, and positive v IAUs are shown in red. The black dashed line indicates the year 1998.

QBO Artifacts and Aura OMI+MLS

- **Fig. 4** (right) shows total column O_3 comparisons with the satellite-based Merged Ozone Dataset (MOD). M2 GMI Replay shows a stable O_3 record; GMI CTM shows a large jump in total O_3 after 1998
- Comparisons of the tracer "ST80_25" (**Fig. 4**, middle) shows that GMI CTM is transporting more air from the mid-stratosphere to the lower stratosphere than M2 GMI Replay
- The tracer differences follow the Quasi-Biennial Oscillation (QBO; **Fig. 4**, bottom panel). The same pattern is observed in total O_3 differences between GMI CTM and satellites in top portion of **Fig. 4**
- GMI CTM transports too much O_3 to the midlatitude LS, particularly during QBO westerlies
- Comparisons with OMI and MLS O_3 show similar model biases associated with the QBO (**Fig. 5**, below). Modeled tropical and midlatitude O_3 biases have opposite phases

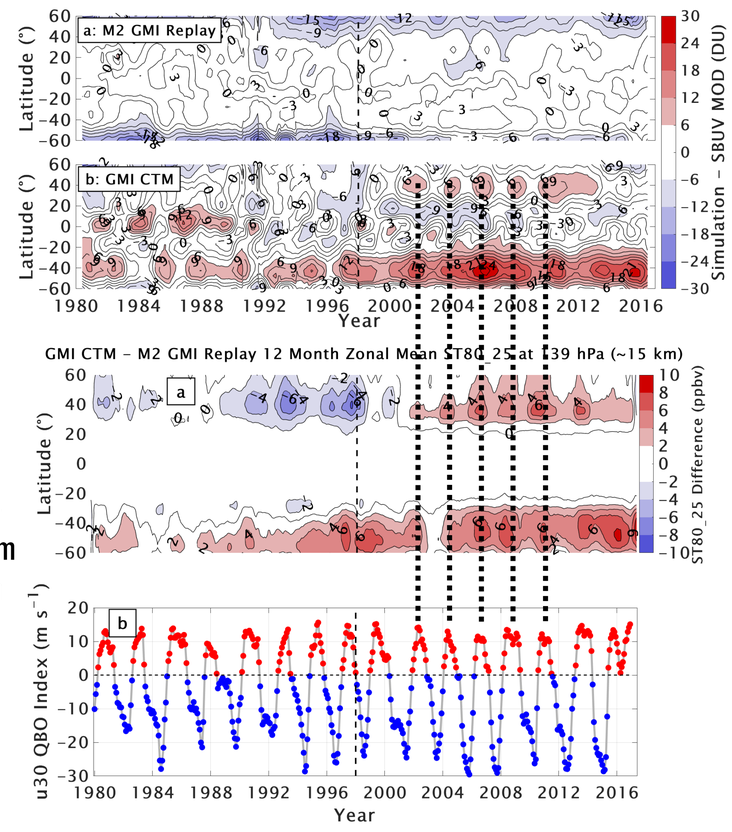

Fig. 4 (**Top two panels**): 12-month zonal means of differences between modeled and SBUV MOD total O_3 columns. Panel (a) shows GMI CTM, and panel (b) shows M2 GMI Replay. (**Middle**): 12-month zonal mean differences in the GMI CTM and M2 GMI Replay ST80_25 stratospheric tracer at the 139 hPa model level. (**Bottom**): The u30 QBO Index colored by positive (red; westerly phase) and negative (blue; easterly phase) values. Dotted lines on the Figure indicate the alignment of peak westerly phase values with maximum differences in ST80_25 tracers and GMI CTM total O_3 biases.

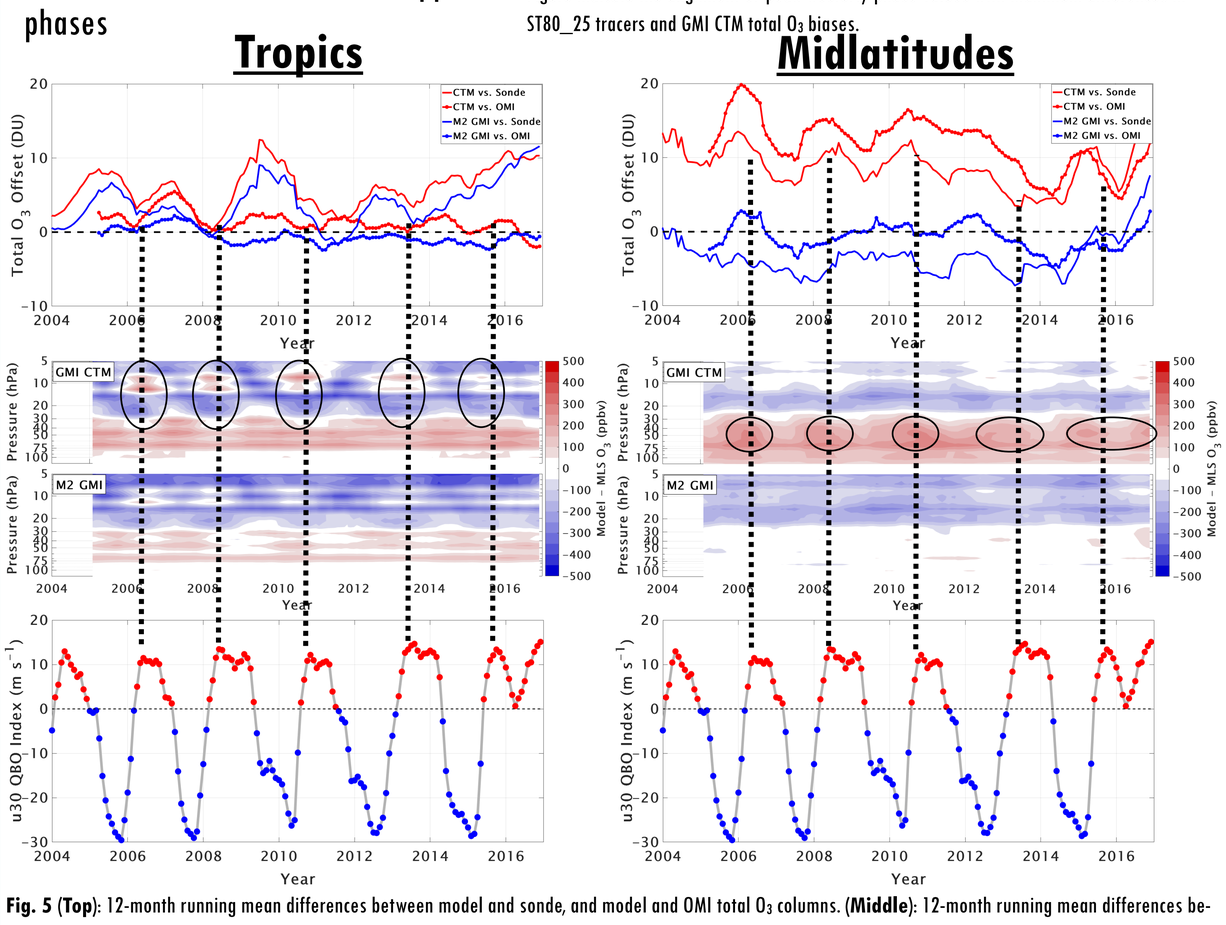

Fig. 5 (**Top**): 12-month running mean differences between model and sonde, and model and OMI total O_3 columns. (**Middle**): 12-month running mean differences between GMI CTM and M2 GMI Replay, and MLS O_3. (**Bottom**): The u30 QBO Index colored by positive (red; westerly phase) and negative (blue; easterly phase) values. Dotted lines on the Figure indicate the alignment of peak westerly phase values with features in modeled O_3 biases. For all panels, tropical sites are on the left, and midlatitudes site are on the right.

Summary/Future Approaches

- The incorporation of ATOVS data into MERRA-2 in 1998 causes a large step change in modeled LS O_3. This is most prevalent in the GMI CTM, which transports too much O_3 to the midlatitudes
- Model total O_3 biases are smallest in the tropics and largest in the midlatitudes during the QBO westerly phase. This indicates that model transport from the tropics to the midlatitudes is too vigorous during QBO westerlies
- We need to investigate potential ATOVS-related changes to model stratospheric circulation, and why M2 GMI Replay appears to be less affected by the assimilation change than GMI CTM

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Select References:

- **This Poster:** Stauffer, R. M., A. M. Thompson, L. D. Oman, and S. E. Strahan (2019), The effects of a 1998 observing system change on MERRA-2-based ozone profile simulations, *J. Geophys. Res. Atmos.*, 124, 7429– 7441. https://doi.org/10.1029/2019JD030257
- **M2 GMI Replay:** Orbe, C., L. D. Oman, S. E. Strahan, et al. (2017), Large-scale atmospheric transport in GEOS replay simulations, *J. Advances in Modeling Earth Systems.*
- **GMI CTM:** Strahan, S. E., A. R. Douglass, and S. D. Steenrod (2016), Chemical and dynamical impacts of stratospheric sudden warmings on Arctic ozone variability, *J. Geophys. Res. Atmos.*